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Effect of Water upon the Tensile Strength of Cement

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EFFECT OF WATER UPON THE TENSILE STRENGH OF CEMENT

...BY...

Thomas Sloan Hewerdine

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1904

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May 27, 1904 190

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

THOMAS SLOAN HEWERDINE

ENTITLED EFFECT OF WATER UPON THE TENSILE STRENGTH OF CEMENT

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Civil Engineering.

Ira O Baker

HEAD OF DEPARTMENT OF Civil Engineering

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There are widely differing opinions concerning the percentage of water to be used in testing hydraulic cement. The U. S. Army Engineers in their report on Testing Hydraulic Cements*, advise the use of 20 per cent of water for neat tests of Portland cement and 30 per cent for natural. Prof. I. O. Baker in his Treatise on Masonry Construction advises† the use of a somewhat higher per cent than is advocated by the Army Engineers. The committee of the American Society of Civil Engineers in a report

* Professional Papers of the Corps of Engineers, U. S. Army. No. 28.

† 9th Edition, p. 70.

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on Uniform Tests of Cement,* advise the use of a cement paste of such consistency that the needle of the Vicat apparatus penetrates 10 mm. (0.39 in.) below the surface. Trial pastes are made with varying percentages of water until the correct consistency is obtained, which is a rather wet paste. Many practicing engineers have the mortar just wet enough so that when well troweled and packed into the mould, there is noticeable a slight surplus of water; while others favor a dryer paste. Some cement manufacturers in their own tests use the per cent of water stated in the report of the U. S. Army Engineers, and

* Progress Report — Presented at the annual meeting Jan. 21st, 1903.

some use a higher or a lower value; while others have no definite rule, but permit the mixer to add water till in his judgment the paste is of the proper consistency. Finally many experimenters use a certain per cent of water regardless of the method of moulding.

Owing to this wide variation in practice, the writer made a series of experiments to determine the relation between strength and the per cent of water used in making neat cement briquettes, and particularly to determine the amount of water that would give the maximum strength.

Before beginning the experiments, it was necessary to decide upon a method of moulding the briquettes. This necessitated the making of a number of preliminary

experiments, which resulted in the adoption of the following method: A quantity of cement necessary for five briquettes was weighed out, the measured amount of water was added, and the cement was thoroughly mixed for about five minutes on a slate table. The moulds were filled in ¼-inch layers, and each layer was carefully pressed in with the fingers and thumbs. The briquettes were covered with a damp cloth and remained in the moulds about 20 hours, when they were removed and placed in water till time for breaking. Immediately after removal from the water, they were broken with a Fairbanks machine.

Tables I to X inclusive show in detail the results obtained for each cement; and

Plates I to VI show these data graphically. Each point plotted represents the mean breaking strength of five briquettes.

From a study of the plates it is seen that the strength increases quite regularly as water is added, until the maximum is reached. An exception to this will be noticed for Portland-cement briquettes broken at 30 days and for part of those broken at 7 days. These show a decided decrease in strength for 18 per cent of water, followed by a gradual increase. The writer offers the following explanation of this decrease: With the lower per cents the briquettes were made by pressing the cement into the moulds with the bare hands; but excessive wear on the thumbs and fingers from making several hundred briquettes, made the wearing of

gloves necessary for the later experiments. With gloves the dryer cement could not be so firmly pressed into the moulds as with the bare hands, and this accounts for the decreased strength. If the moulding had been continued as at first, it is probable that a maximum would have been found with a smaller per cent of water, and also that a greater tensile strength would have been obtained.

It is certain that hard pressing, or better, the ramming of the cement into the moulds greatly increases the strength. In some experiments made by the writer in which the cement was rammed firmly into the moulds, a maximum strength was obtained with 3 per cent less water than was necessary for a maximum when the cement was pressed

into the moulds with the fingers, and the resulting tensile strength was one-third greater.

Whatever the method of moulding, the per cent of water required to produce a maximum strength varies with each cement, and with different lots of the same cement, both natural and Portland. Also, old cement requires less water than new. A point in favor of the very plastic paste is that it can be more readily mixed than a stiff one; and further, more uniform results are obtained with the former than with the latter.

If more than a certain amount of water is used, and the cement becomes too wet, ramming will have little or no effect; and on the other hand, if the cement is comparatively dry and the pressing

or ramming is not heavy enough to compact it, low strength and lack of uniformity will be the result. In other words, to secure the greatest strength for any given method of moulding, just enough water should be used to bring the cement to that consistency at which it may be compacted into the moulds most firmly.

TABLE-I.

Atlas Portland Cement.

Per Cent Water	Tensile Strength in Pounds per Square Inch.																	
	Age: 1 Day.						Age: 7 Days						Age: 30 Days					
	Briquettes.					Mean	Briquettes.					Mean	Briquettes					Mean
13	136	138	135	154	147	142	340	361	430	329	368	365	486	448	520	477	449	476
14	160	135	140	141	163	148	428	376	342	419	419	397	500	510	482	610	555	531
15	164	177	170	174	166	170	445	411	453	393	443	429	538	496	567	576	634	562
16	141	178	234	200	170	185	499	452	419	483	448	460	725	701	673	635	725	692
17	270	320	323	252	240	281	570	529	523	512	617	550	630	663	751	802	722	713
18	302	303	315	301	298	304	523	614	471	524	512	529	652	672	705	669	765	693
19	302	292	289	290	286	292	609	677	607	620	610	625	768	771	750	754	632	735
20	296	295	293	291	295	294	605	560	519	616	520	564	704	633	683	653	673	649
21	275	273	275	271	272	273	590	597	617	575	541	584	655	683	635	650	565	638
22	262	263	253	252	253	261	561	496	501	517	499	515	599	594	668	557	640	612
23	254	275	260	266	256	262	431	447	495	429	465	453	521	531	609	505	518	537
24	266	265	274	278	277	272	473	404	422	432	412	429	514	528	449	511	543	509

TABLE-II.

Chicago AA Portland Cement.

Per Cent Water.	Tensile Strength in Pounds per Square Inch.																	
	Age: 1 Day.						Age: 7 Days.						Age: 30 Days.					
	Briquettes.					Mean.	Briquettes.					Mean.	Briquettes.					Mean.
13	153	163	136	143	130	145	286	315	346	335	311	319	482	494	535	490	490	498
14	202	150	176	190	191	182	456	355	385	403	335	387	470	470	490	495	500	495
15	170	186	145	185	204	178	482	442	400	402	475	440	483	495	575	558	512	525
16	207	193	195	211	198	201	460	524	438	411	460	459	497	554	643	550	545	558
17	245	320	190	205	209	214	416	470	431	497	472	457	628	598	603	610	593	606
18	263	251	258	253	165	238	476	399	479	490	492	467	520	508	563	496	588	534
19	274	269	271	264	355	287	478	458	528	467	558	498	776	546	651	601	748	664
20	348	255	264	250	252	274	515	481	503	492	463	491	789	907	702	729	652	756
21	290	288	306	282	294	292	475	584	468	596	511	527	850	907	833	864	817	854
22	316	301	388	298	307	322	562	514	598	548	583	561	874	925	795	712	937	849
25							597	540	484	614	566	560						

TABLE-III.

Alpha Portland Cement.

Per Cent Water	Tensile Strength in Pounds per Square Inch.																	
	Age: 1 Day						Age: 7 Days						Age: 30 Days					
	Briquettes					Mean	Briquettes					Mean	Briquettes					Mean
13	160	125	145	150	135	143	335	407	389	390	454	395	518	450	550	327	565	482
14	170	175	175	180	165	173	509	473	479	427	403	458	520	496	575	590	455	527
15	200	196	214	123	197	186	421	504	568	464	458	483	499	591	611	515	502	544
16	210	188	219	130	202	190	456	530	544	470	450	490	640	512	593	671	564	596
17	198	308	297	307	326	287	513	494	532	493	449	496	637	703	654	605	621	644
18	286	291	290	307	300	295	475	423	376	370	358	400	677	779	660	636	696	690
19	323	243	329	268	314	296	516	575	701	494	555	588	755	700	657	681	695	698
20	215	307	319	225	321	277	650	748	706	756	678	708	770	672	782	764	737	745
21	310	341	252	325	353	316	711	775	686	677	724	715	813	776	838	793	789	802
22	266	355	270	335	268	298	818	621	765	596	760	712	647	782	709	750	722	722
24							563	557	670	601	523	583						

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TABLE-IV.

Medusa Portland Cement.

Per Cent Water	Tensile Strength in Pounds per Square Inch																	
	Age: 1 Day						Age: 7 Days.						Age: 30 Days.					
	Briquettes					Mean	Briquettes					Mean	Briquetts					Mean
13	151	122	130	146	139	138	351	427	390	328	322	363	470	532	420	418	387	458
14	168	131	142	149	159	150	397	390	424	367	370	389	529	538	517	518	539	528
15	165	253	159	172	157	181	352	451	440	439	380	412	494	627	522	581	519	549
16	202	171	225	163	197	192	313	490	426	492	472	438	638	646	594	546	576	600
17	351	267	207	270	252	269	487	533	425	485	494	485	733	695	653	685	655	684
18	283	374	282	283	273	299	584	390	490	507	501	494	500	705	695	777	753	686
19	366	363	279	277	367	331	663	642	619	643	647	643	817	766	778	608	541	702
20	371	291	376	287	361	337	665	609	597	634	705	642	637	773	653	751	538	670
21	362	266	365	335	289	323	624	526	568	677	581	595	800	765	825	877	920	837
22	348	355	265	354	362	337	526	562	623	577	590	576	735	877	828	788	772	802

TABLE-V.

Universal Portland Cement.

Per Cent Water	Tensile Strength in Pounds per Square Inch.																	
	Age: 1 Day.						Age: 7 Days.						Age: 30 Days.					
	Briquettes.					Mean.	Briquettes.					Mean.	Briquettes.					Mean.
14	172	167	165	180	163	169	270	241	266	291	310	276	382	400	327	329	357	359
15	181	191	182	187	185	185	298	212	304	261	325	282	367	400	338	323	417	369
16	184	179	179	160	185	177	266	309	251	310	261	274	419	312	352	332	406	365
17	167	165	193	175	182	176	327	450	336	308	400	364	431	458	399	495	358	426
18	184	187	183	192	196	188	350	348	376	338	422	367	445	404	447	435	449	436
19	195	209	193	190	202	198	375	440	438	405	428	417	466	427	400	437	468	440
20	203	199	207	185	199	185	427	473	402	326	425	413	550	495	528	499	542	523
21	194	187	220	200	258	212	490	451	477	507	422	469	477	462	559	646	528	534
22	222	215	220	232	213	222	471	492	515	408	571	491	695	565	663	663	781	673
23	224	213	192	262	217	222	408	434	453	501	427	455	660	695	741	737	791	725
24	226	200	224	235	247	226	362	352	393	443	421	394	623	605	558	653	579	604
25	215	202	211	210	200	208	319	416	367	389	410	380	606	580	687	548	597	604

TABLE-VI.

Vulcanite Portland Cement.

Per Cent Water	Tensile Strength in Pounds per Square Inch.																	
	Age: 1 Day.						Age: 7 Days.						Age: 30 Days.					
	Briquettes					Mean	Briquettes					Mean	Briquettes					Mean
13	148	163	170	159	162	160	357	337	317	361	360	346	595	632	655	630	609	624
14	182	180	176	171	153	172	356	325	381	400	383	369	630	576	657	660	628	630
15	162	181	190	161	162	171	391	411	432	352	385	394	650	640	610	591	613	621
16	168	165	145	153	174	161	465	450	516	503	520	491	678	683	650	592	580	637
17	175	167	262	185	269	212	650	530	495	575	526	555	650	673	695	656	701	655
18	173	168	168	257	202	194	400	460	486	503	501	570	582	685	591	501	682	608
19	215	210	217	215	209	213	595	530	595	511	600	566	532	505	638	500	545	544
20	198	184	205	200	195	196	644	625	583	618	698	634	698	653	703	685	613	670
21	263	210	227	218	216	227	651	565	727	627	659	646	740	694	744	805	772	751
22	217	320	218	295	274	265	548	520	459	573	497	519	715	840	820	797	810	796
23	204	299	308	200	239	250	469	586	496	505	550	521	703	630	695	673	643	669
25	237	221	248	320	245	254	704	550	717	568	485	605	751	654	655	570	593	645

TABLE-VII.

N.Y.& Rosendale Natural Cement.

Per Cent Water	Tensile Strength in Pounds per Square Inch.																	
	Age: 1 Day.						Age: 7 Days.						Age: 30 Days.					
	Briquettes.					Mean.	Briquettes.					Mean.	Briquettes.					Mean.
28	88	87	79	94	98	89	102	111	124	117	106	112	186	260	256	230	233	233
29	84	82	87	86	86	85	118	123	98	112	136	118	192	217	200	224	240	215
30	94	78	79	96	86	87	100	122	122	114	119	116	235	230	264	253	230	243
31	85	99	92	86	85	90	114	108	108	98	124	111	237	217	253	247	275	246
32	79	81	89	74	78	80	93	97	98	97	81	93	261	250	276	240	215	249
33	80	73	75	73	77	76	100	98	98	110	91	100	235	237	235	212	213	227
34	69	82	61	65	60	68	87	76	94	86	101	89	184	193	203	227	243	210

TABLE-VIII.

Louisville Natural Cement.

Per Cent Water.	Tensile Strength in Pounds per Square Inch.																	
	Age: 1 Day.						Age: 7 Days.						Age: 30 Days.					
	Briquettes.					Mean.	Briquettes.					Mean.	Briquettes.					Mean.
31	57	58	61	62	59	59	61	57	63	64	83	66	174	143	208	198	199	184
32	57	61	63	66	53	60	62	73	89	62	90	75	203	207	229	220	213	214
33	75	65	73	62	67	69	70	91	86	91	86	83	234	225	229	192	216	219
34	75	72	71	67	74	72	93	83	117	93	80	93	217	216	222	185	201	208
35	107	94	78	90	93	93	93	120	98	92	114	104	229	179	215	226	246	219
36	97	100	104	108	90	100	105	105	100	98	108	103	202	210	238	219	216	217
37	101	102	99	100	93	99	110	105	113	121	94	109	236	208	225	189	204	212
38	90	97	105	91	95	96	107	90	111	100	97	101	220	209	221	207	204	212

TABLE-IX.

Utica Natural Cement.

Per Cent Water.	Tensile Strength in Pounds per Square Inch.																	
	Age: 1 Day.						Age: 7 Days.						Age: 30 Days.					
	Briquettes.					Mean.	Briquettes.					Mean.	Briquettes.					Mean.
30	61	54	57	76	63	62	84	95	86	88	93	89	196	212	222	195	146	194
31	59	65	70	52	69	63	120	138	131	142	149	136	220	209	202	165	193	198
32	73	76	68	82	83	76	163	184	147	152	163	162	192	262	230	232	236	230
33	66	67	62	77	62	67	175	189	147	178	174	171	250	206	265	248	246	243
34	90	85	76	80	88	84	112	107	132	106	111	114	205	237	210	224	234	222
35	71	57	69	73	70	68	188	244	179	188	165	193	290	243	298	210	249	258
36	74	63	70	64	70	68	210	218	191	175	202	199	248	250	225	180	248	230
37	65	66	40	60	53	57	116	131	120	129	107	121						
38	83	85	81	77	110	87	150	148	152	158	165	155						

TABLE-X.

Milwaukee Natural Cement.

Per Cent Water.	Tensile Strength in Pounds per Square Inch.																	
	Age: 1 Day.						Age: 7 Days.						Age: 30 Days.					
	Briquettes.					Mean.	Briquettes.					Mean.	Briquettes.					Mean.
30	57	56	54	50	52	54	67	71	63	54	70	65	91	104	100	98	85	96
31	56	55	60	66	69	61	57	84	63	63	57	65	94	84	84	96	99	91
32	57	67	75	63	62	65	59	62	64	61	75	64	89	111	102	85	102	98
33	65	60	64	63	61	63	65	71	64	57	73	66	216	202	177	204	205	201
34	74	72	74	68	63	70	70	65	67	68	74	69	202	207	230	193	220	210
35	83	68	77	85	73	77	66	58	56	60	75	63	264	247	221	232	140	221
36	73	72	77	81	79	76	66	63	60	66	62	63	217	220	204	192	116	190
37							60	50	59	65	61	59						

PLATE I. Age: 1 Day.

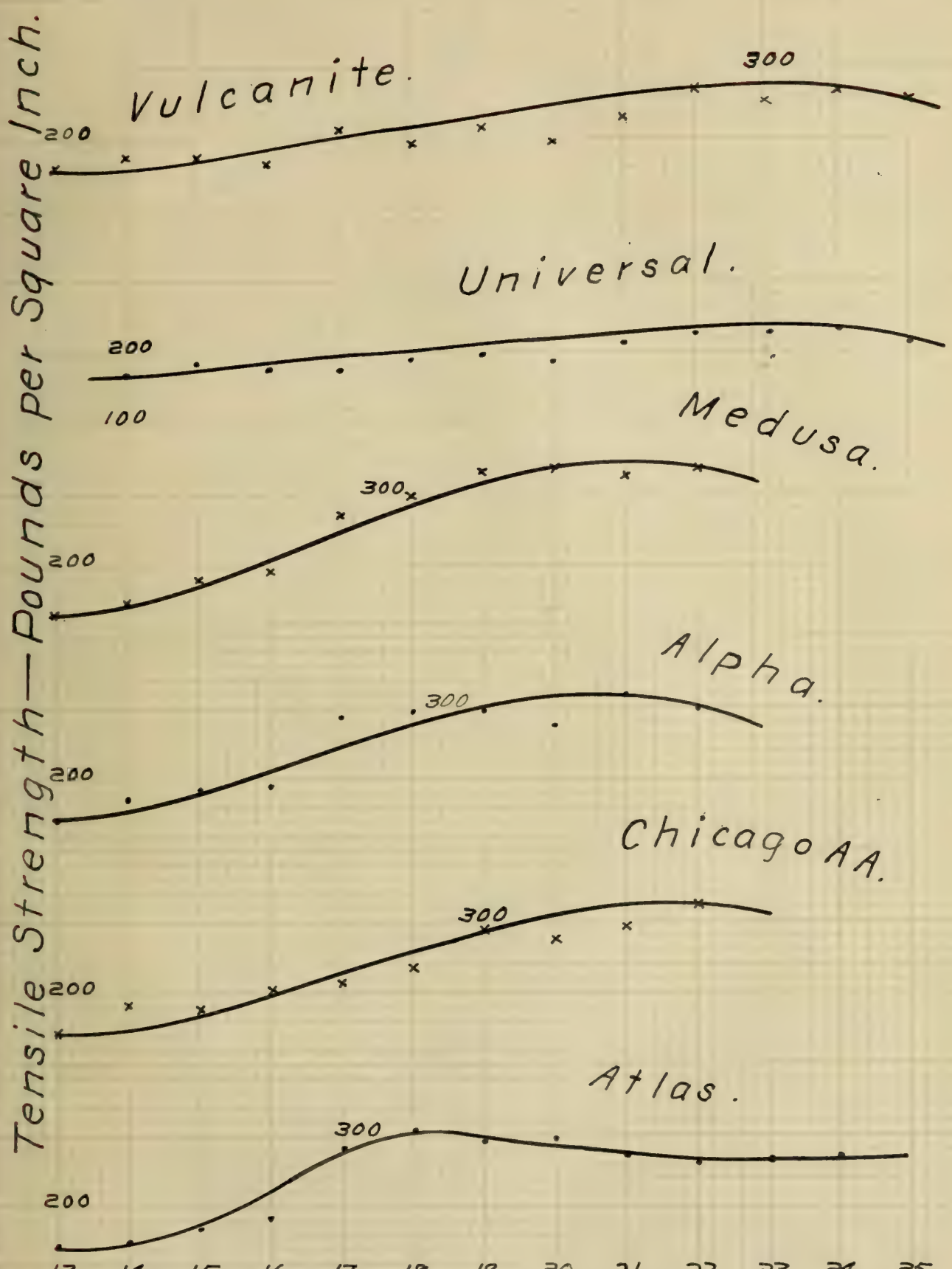


PLATE-II. Age: 7 Days.

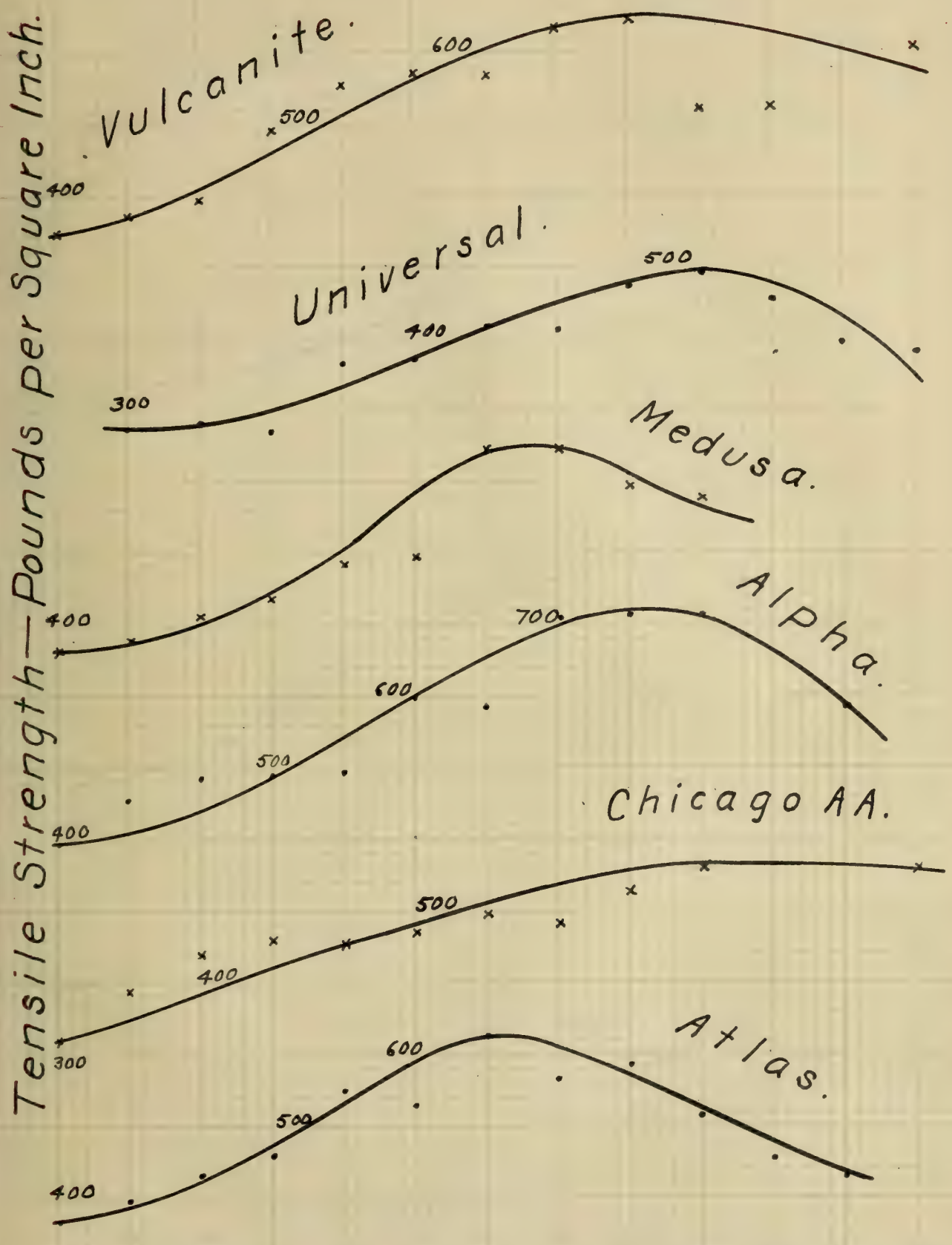
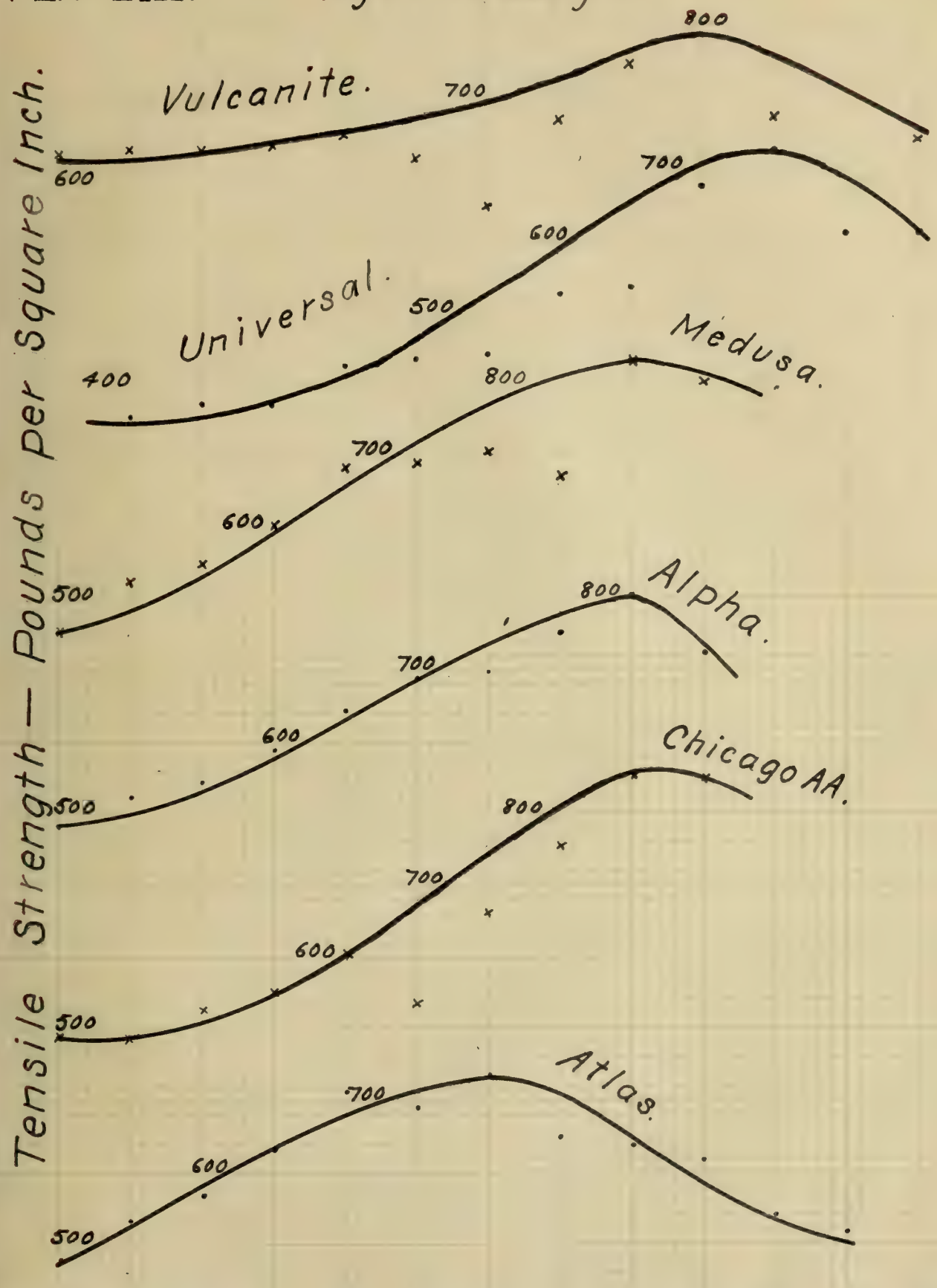


PLATE-III. Age: 30 Days.



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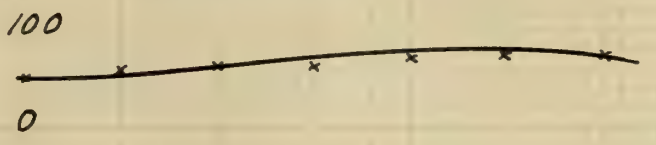
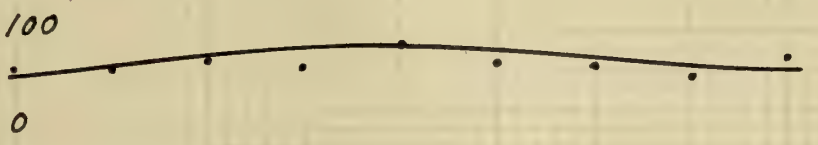
Tensile Strength — Pounds per Square Inch.

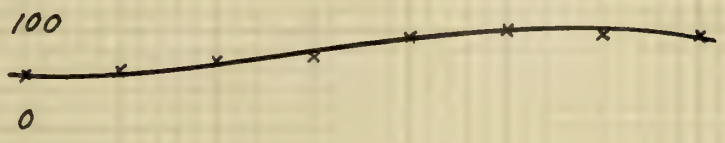
Milwaukee.



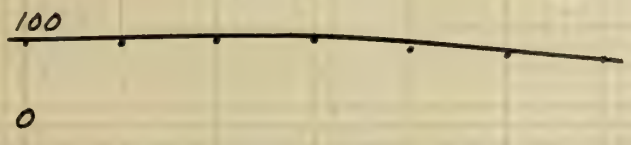
Utica.



Louisville.



N.Y.& Rosendale.



28 29 30 31 32 33 34 35 36 37 38

Per Cent of Water.

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PLATE-V. Age: 7 Days.

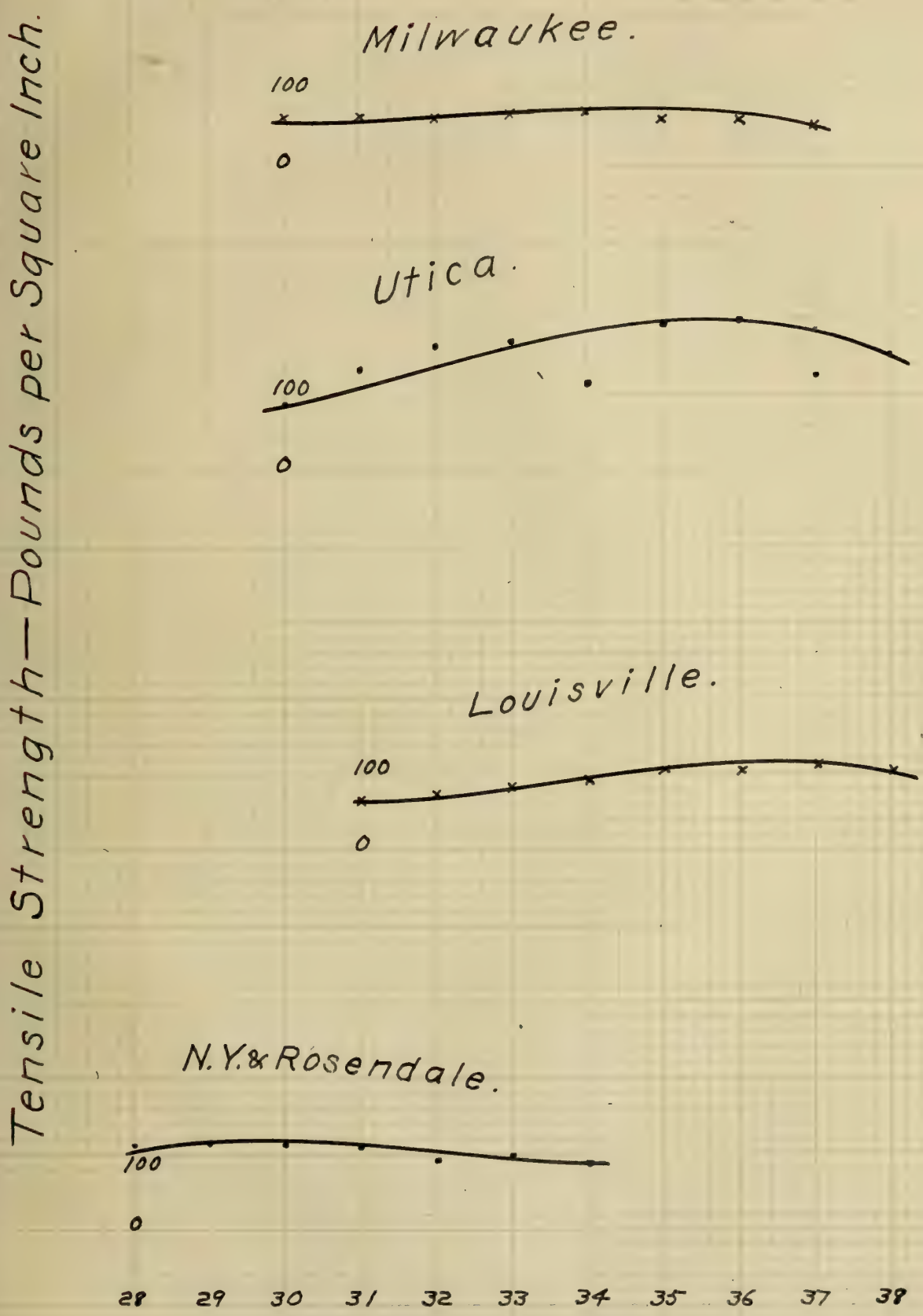
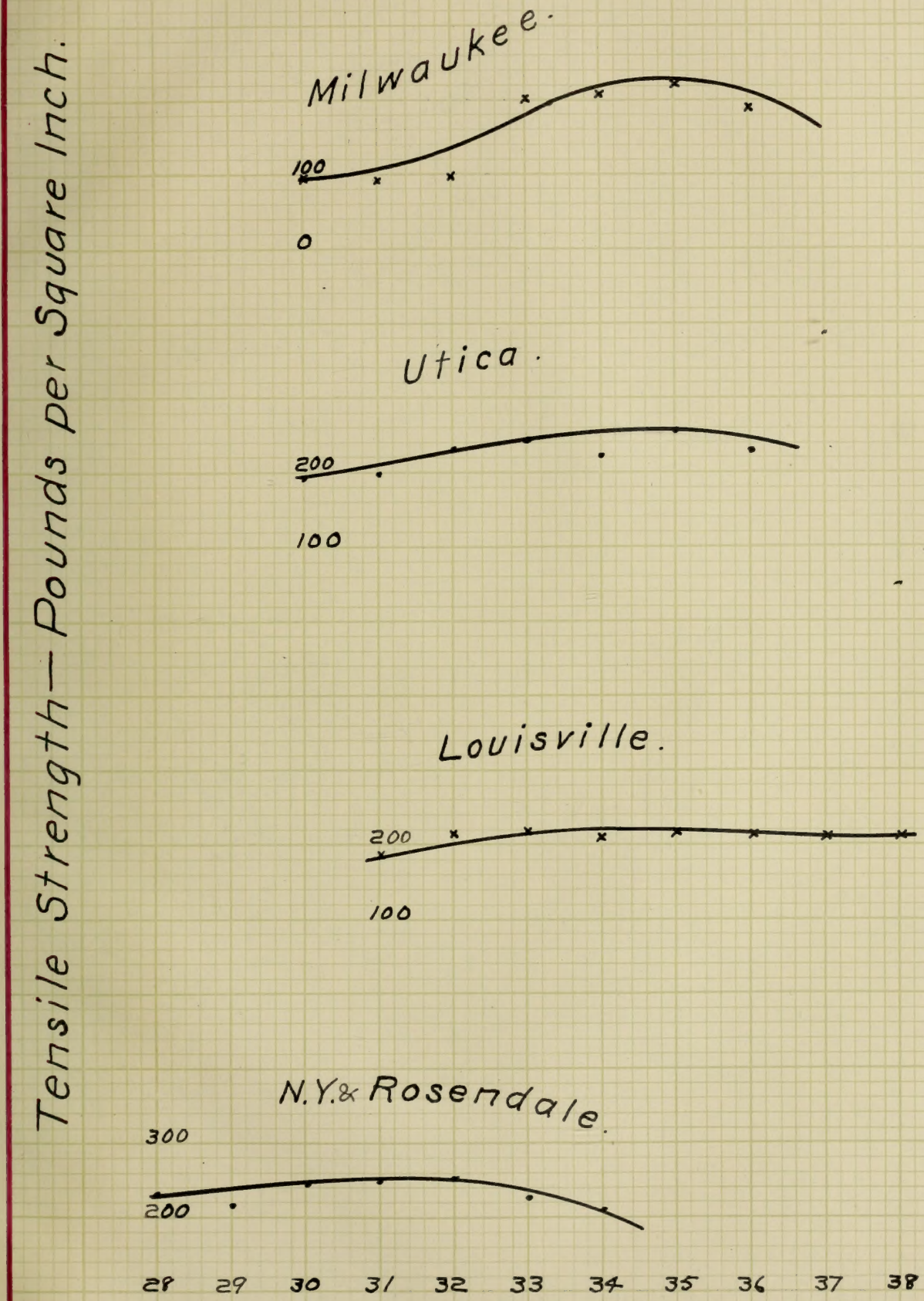


PLATE-VI. Age: 30 Days.



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